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Automated Data Acquisition and Control System Bolsters EPA's (Environmental Protection Agency's) Air Pollution Research

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The introduction of advanced microcomputer technology to the research laboratory has enhanced the way scientists design and perform experiments. Here at the Environmental Research Laboratory of the U.S. Environmental Protection Agency in Corvallis, Oregon, we are researching the effects of air pollutants on agricultural and native plant species. We are capable of performing studies directly related to ambient air quality due to this microcomputer technology.

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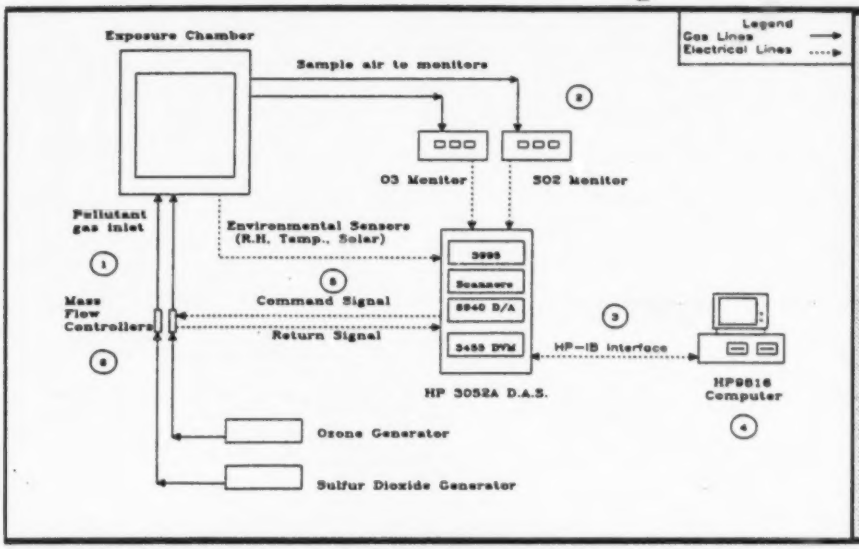
Application

Automated data acquisition and control system bolsters EPA's air pollution research



1. The pollutant enters the chamber through the mass flow controller.
2. The pollutant concentration is sampled by a pollutant monitor.
3. The HP 9816 reads the monitor through the HP 3995A Scanner and the HP 3455 DVM.
4. The computer compares the actual concentration with the request and calculates any necessary flow adjustment.
5. The computer sends the new command through the HP 6940 multiprogrammer to the flow controller.
6. The flow controller adjusts the pollutant flow and the resulting concentration in the chamber.

Figure 1 *Schematic of exposure control and data acquisition system. Circled numbers indicate the location of the six steps in the control feedback loop.*

By Peter K. Ziminski and Steven R. Holman

The introduction of advanced microcomputer technology to the research laboratory has enhanced the way scientists design and perform experiments. Here at the Environmental Research Laboratory of the US Environmental Protection Agency in Corvallis, Oregon, we are researching the effects of air pollutants on agricultural and native plant species. We are capable of performing studies directly related to ambient air quality due to this microcomputer technology.

System design

We have designed an automated pollutant exposure system based on HP computers and instruments, which allows us to examine the impact of "realistic" 0_3 and $S0_2$ pollutant exposure on plants. This system is capable of delivering, monitoring, and controlling 0_3, $S0_2$ or other pollutants, individually or in combination, within specially designed exposure chambers. Additionally, the system acquires solar radiation, air temperature and relative humidity data. With this system, plants can be exposed to a continually changing concentration of gaseous pollutants 24 hours per day with full monitoring of environmental conditions. The gas concentrations we used in our studies are hourly averages modeled after actual ambient air quality data.

The experimental plants are contained in eight exposure chambers located within a greenhouse facility that provides stable air temperatures and supplemental solar radiation. The chambers are connected to a common exhaust fan providing each with a constant flow of charcoal-filtered air. Ports are provided at the air inlet of each chamber to allow the injection of pollutant gases. A separate room houses the air pollutant monitors, data acquisition and control system.

A Hewlett-Packard Series 200 Model 9816 handles all the pollutant data acquisition and control functions required by the system.

Ours hosts 512K of RAM, a 9-inch monochrome monitor, an HP 9122 dual disk drive and the enhanced keyboard option. We selected the HP 9816 from several models offered by HP and other manufacturers for four reasons:

- expandability (up to 4Mb RAM)
- built-in HP-IB (IEEE-488) and RS-232 interfaces
- graphics capabilities
- built-in I/O capabilities

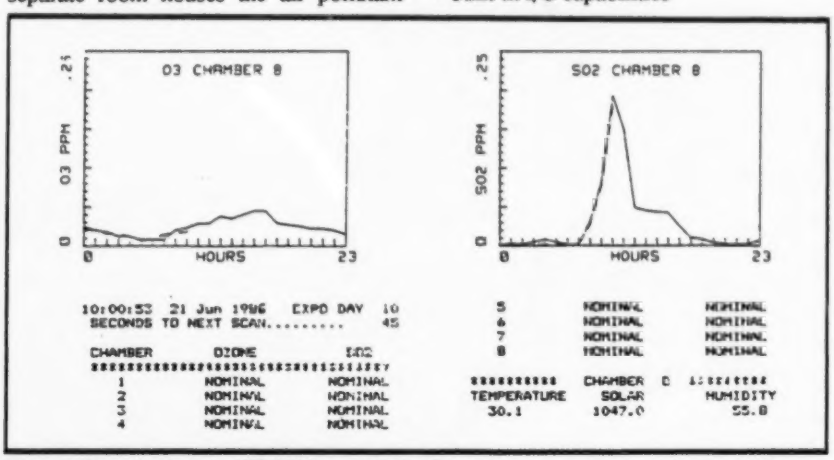


Figure 2 *Example of a typical HP 9816 status display. The solid line represents the requested pollutant concentration and the dashed line represents the actual concentration.*

Our system operation can be separated into two essential functions: data acquisition and pollutant control.

Data acquisition

Pollutant concentrations and environmental data in the chambers are collected through an HP 3052A Data Acquisition System (DAS). The DAS consists of three HP 3995A Multichannel Scanners, a HP 6940B Multiprogrammer, and an HP 3455 Digital Voltmeter (DVM).

The three scanners in the system provide 120 possible data input channels. All air temperature, relative humidity, solar radiation and pollutant sensors are connected to these channels. The 9816 accesses these channels approximately once a minute. From these data, daily chamber air temperature, relative humidity and solar radiation data summaries are constructed. At midnight, the previous day's data are stored on disk. Then, the 9816 uses the RS-232 port and a modem to dial up our main computer, a DEC PDP 11/70, and transmits the data to that system. We can then summarize the data on the PDP 11/70 without interrupting the 9816.

Our system operation can be separated into two essential functions: data acquisition and pollutant control.

Pollutant control

Pollutant gas enters the chamber through a mass flow controller. This is an electronic device used to precisely measure and control gas flow. The device senses the flow of gas, and generates a voltage (called the return signal) proportional to that flow. It receives a voltage (called the command signal) from an external controller, and adjusts the gas flow so that the return and command signals match.

Each exposure chamber is equipped with two mass flow controllers, one for 0_3 and one for $S0_2$. Once every minute, the 9816 calculates the appropriate command signal for each device. The calculation is based on a simple algorithm relating the current requested pollutant concentration, the actual concentration in the chamber and the current mass flow into the chamber.

The 9816 transmits this command signal in digital form to an HP 6940 Multiprogrammer that contains several digital to analog (D/A) convertors. Each mass flow controller is connected to one of these convertors. The digital command signal is converted to the appropriate voltage signal and sent to the flow controller, which then adjusts the pollutant flow and changes the chamber concentration. Thus, this control system follows the six steps of the simple feedback loop shown in Figure 1.

Software

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system, we had to design our own software. We chose Hewlett-Packard Basic 3.0 because our application does not require the execution speed of a compiled language like Pascal.

When designing the software, we had two primary goals. The first was to provide information that would allow the operator to assess system performance at a glance; the second, to program fail-safe routines that would allow the system to deal with power failures and equipment malfunctions without operator attention.

With the 9816's graphic capabilities, providing system performance information was easily accomplished. Figure 2 illustrates the monitor display we use for this purpose.

At the start of each day, the requested profiles for each chamber are read from disk and stored in memory. The requested 0_3 and $S0_2$ profiles for one chamber are plotted on the screen as solid lines, while a second, dashed line is plotted on each graph, representing the actual hourly average pollutant concentration in that chamber. As the day progresses, this line advances across the screen, giving a clear indication of how well the system is performing.

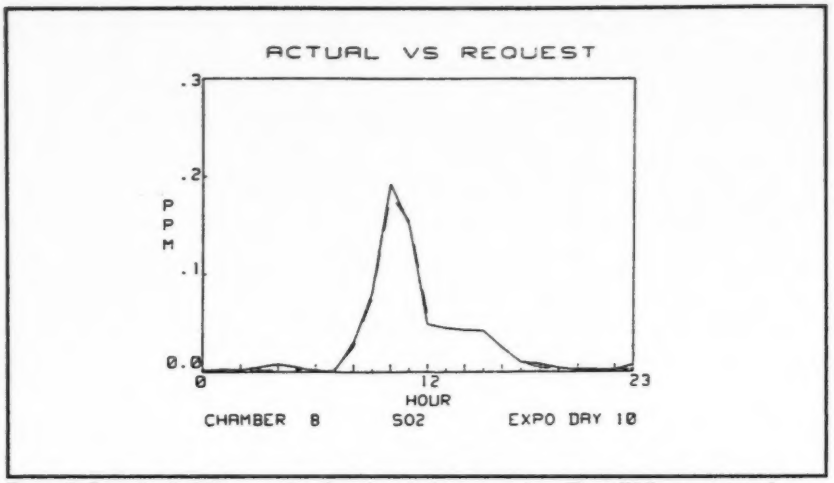


Figure 3 *Example of a full-screen plot of previous day's exposure data. The solid line represents the requested pollutant concentration and the dashed line represents the actual concentration.*

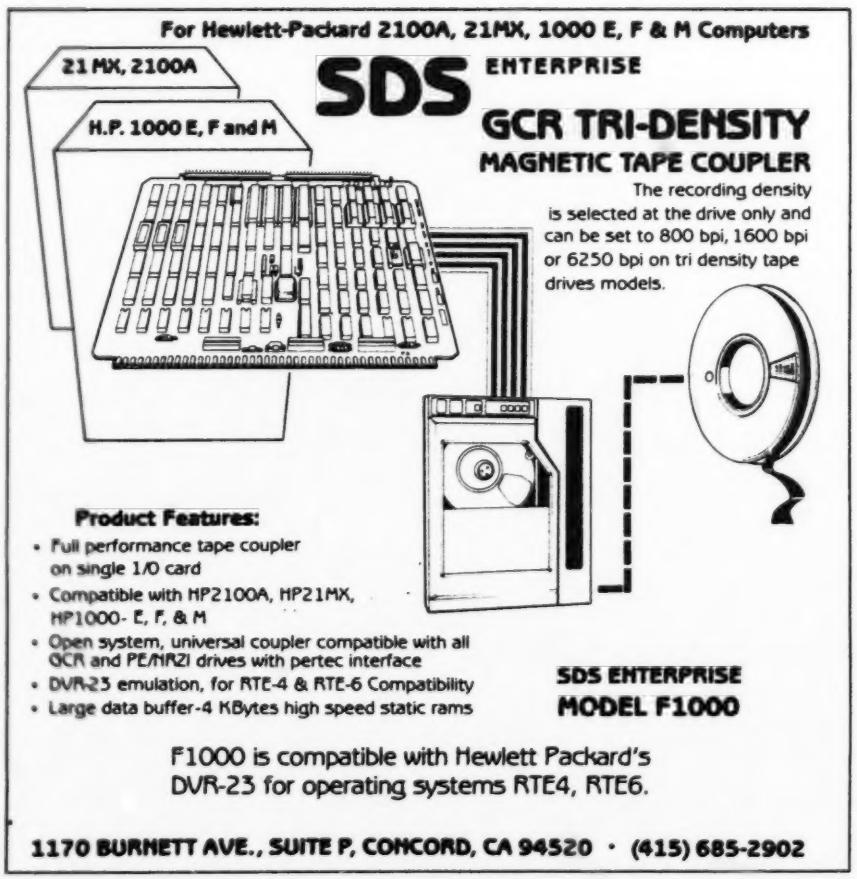
Approximately once a minute, after the computer scans the input channels, the screen display is updated and another chamber plotted. In addition to the plots, the current exposure status of all chambers is presented in text form. These data represent the last concentration scan for each chamber and are listed as either being *high* (if greater than the requested value), *low* (if less than this value) or *nominal* (if equal to the requested value).

Environmental data for the chamber plotted on the monitor are displayed along with the date, time, elapsed number of exposure days, and the number of seconds until the next data scan.

The system is designed to run unattended 24 hours a day for extended periods. To detect potential problems and ensure data quality, it is necessary to review the previous day's data. Although the data are sent to the PDP 11/70 nightly, it is more convenient to examine a data plot on the 9816 than it is to comb through a series of numbers on a printout for these simple qualitative checks.

To accomplish this, we wrote a routine to display a full-screen plot of any previous days' data. An example plot is shown in Figure 3. This routine can be accessed at any time from the 9816's softkey pad.

Since power failures result in loss of all data currently stored in RAM, and can mean the loss of large blocks of data, it was extremely important for us to accomplish our second goal—programming the system to deal with power failures, etc. To do this, the computer is connected to a power supply which can provide backup power for approximately four minutes. This is generally long enough to outlast most power interruptions. However, to safeguard against longer power failures, we took another precaution: while the system is operating, all data currently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stored in RAM are copied to a single disk file at the beginning of each hour. The file is written over every hour with the updated data, current date and time. After a long power failure, the 9816 uses its auto-start feature to boot itself and run the exposure program. At the start of the program, the hourly data file is read, the clock is reset, and all variables are loaded with their previous values and the exposure continues. Thus, no more than one hour of previously collected data can be lost.

In a feedback loop, system performance is dependent upon the correct operation of the primary sensors. In our system, these are the 03 and S02 monitors. If a pollutant monitor fails, the computer reads the concentration as being zero and then opens the mass flow controller. As long as the monitor does not respond, this cycle will continue and an overexposure will result. To avoid this problem, the computer constantly compares the pollutant flow into the chamber with the pollutant concentration inside. If the flow into the chamber is high and the concentration low, the system will assume a monitor failure, automatically shut off the gas to all chambers, display an error message, and wait to be manually restarted.

At our HP-based facility, we are using recent advances in data acquisition and process control technology to uncover detailed information about how plants respond to air pollutants.

It is not always desirable to shut the system down every time a device fails as long as the pollutant control is not compromised. For example, at midnight after the 9816 has stored data on disk, it attempts to send the data to the PDP 11/70. If the PDP 11/70 does not respond, we have designed the software to abort the data-send routine, print a message indicating the problem and continue with the main program. The data can be sent at a later date using another routine accessed with the softkey pad.

System performance

We routinely perform a full system evaluation at the end of each experiment in two ways. The first is to plot a histogram of the hourly difference between the actual delivered pollutant concentrations and the requested concentrations. We also sum the hourly requested concentrations over the entire experiment and compare that to the sum of the actual concentrations.

The first method provides an assessment of the hourly deviations of the control system and the second gives an integrated measurement of deviations for the whole experiment.

For the experiments performed to date, the requested 0_3 concentrations range from 0.003 parts per million (ppm) to 0.288 ppm, and for $S0_2$ from 0.000 ppm to 0.193 ppm. More than 90 percent of our hourly chamber concentrations have been within 0.01 ppm of the requested value. The difference between the actual and requested sums has been less than 10 percent.

The accuracy of these values leads us to the knowledge that this HP-based pollutant exposure facility, using recent advances in microcomputer, data acquisition and process control technology, allows us to address detailed questions about how plants respond to air pollutants. The answers to these questions will bring us closer to understanding the potential impacts of our activities on the natural world.♦

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